## Claims

What is claimed is:

1. A method of conditioning a planarizing surface in a chemical mechanical polishing (CMP) apparatus having a polishing pad against which a wafer is positioned for removal of material therefrom and a conditioning disk is positioned for conditioning of the polishing pad, comprising the steps of:

a) providing a pad wear and conditioning model that defines wafer material removal rate as a function of at least one pad conditioning parameters, said at least one conditioning parameter having maximum and minimum values;

b) polishing a wafer in the CMP apparatus under a first set of pad conditioning parameters selected to maintain wafer material removal rates within preselected minimum and maximum removal rates;

c) determining a wafer material removal rate occurring during said polishing step;

d) calculating updated pad conditioning parameters based upon said determined wafer material removal rate of said step (c) and the pad wear and conditioning model to maintain wafer material removal rates within the maximum and minimum removal rates; and

e) conditioning the polishing pad using the updated conditioning parameters.

2. The method of claim 1, wherein the conditioning parameters comprise conditioning down force.

3. The method of claim 2, wherein the conditioning parameters comprise rotational velocity of the conditioning disk.

4. The method of claim 2, wherein the conditioning parameters comprise one or more parameters selected from the group consisting of rotational velocity of the disk, frequency of conditioning, duration of conditioning and translational speed of the conditioning disk.

5. The method of claim 1, wherein the step of calculating updated conditioning parameters includes calculating parameters such that the parameter is within the determined minimum and maximum values.

6. The method of claim 1, wherein the updated pad conditioning parameters are calculated by determining the difference between an output of the pad wear and conditioning model and said determined wafer material removal of step (c).

7. The method of claim 6, wherein said difference is adjusted using an estimate gain prior to calculating updated conditioning parameters.

8. The method of claim 1, wherein the updated pad conditioning parameters are updated according to the equation $k = (k_1) + g * (k - (k_1))$, where $k$ is a measured wafer material removal rate, $k_1$, is a calculated wafer material removal rate, $g$ is the estimate gain, and $(k-(k_1))$ is the prediction error.

9. The method of claim 1, wherein the steps b) through e) are repeated.

10. The method of claim 1, wherein the first set of pad conditioning parameters are determined empirically.

11. The method of claim 1, wherein the first set of pad conditioning parameters are determined using historical data.

12. The method of claim 1, wherein the first set of pad conditioning parameters are determined using the results of a design of experiment (DOE) used to develop the model.

13. The method of claim 1, wherein the maximum value for wafer material removal rate is the saturation point of the wafer material removal rate vs. conditioning down force curve.

14. The method of claim 1, wherein the minimum value for wafer material removal rate is defined by the maximum acceptable wafer polishing time.

15. The method of claim 1, wherein the step of calculating updated pad conditioning parameters in step (d) comprises executing a recursive optimization process.

16. The method of claim 7, wherein the estimate gain is an indication of variability or reliability in the measured parameter.

17. The method of claim 1, wherein pad life is defined according to the equation:

$$PadLife = f\left(F_{disk}, \omega_{disk}, t_{conditioning}, f, T_2\right),$$

where $F_{disk}$ is the down force applied by the conditioning disk to the CMP pad during conditioning, $\omega_{disk}$ is the angular velocity of the conditioning disk during conditioning of the polishing pad, $t$ is the time of conditioning, $f$ is the frequency of condition and $T_2$ is the sweeping speed of the conditioning disk during conditioning.

18. The method of claim 1, wherein the wafer material removal rate is defined by the equation

$$\mathrm{Re}\,movalRate\Big]_{\min}^{\max} = f\left(F_{disk}\Big]_{\min}^{\max}, \omega_{disk}\Big]_{\min}^{\max}, f\Big]_{\min}^{\max}, t_{conditioning}\Big]_{\min}^{\max}, T_2\Big]_{\min}^{\max}\right),$$

where $F_{disk}$ is the down force applied by the conditioning disk to the CMP pad during conditioning, $\omega_{disk}$ is the angular velocity of the conditioning disk during conditioning of the polishing pad, $t$ is the time of conditioning, $f$ is the frequency of condition, and $T_2$ is the sweeping speed of the conditioning disk during conditioning.

19. The method of claim 1, wherein the wafer material removal rate is determined according to the equation:

$$\hat{y}_i = \rho_i x_i + I_i,$$

where $\hat{y}_i$ is the wafer material removal rate for a conditioning parameter $x_i$, $\rho_i$ is the slope and $I_i$ is the intercept of the curve of the defining the relationship between $\hat{y}_i$ and $x_i$.

20. The method of claim 19, wherein the updated pad conditioning parameter, $x_{i+}$, is determined by solving the equation:

$$x_{i+} = \frac{\hat{y}_{i+} - I_i - \frac{W_i}{W_T} \cdot \Delta\hat{y}}{\rho_i},$$

where $\hat{y}_{i+}$ is the target wafer material removal rate, $W_i$ is the weighing factor for conditioning parameter $x_i$, and $\Delta y$ is the prediction error for wafer material removal rate.

21. An apparatus for conditioning polishing pads used to planarize substrates by the removal of material therefrom, comprising:

a carrier assembly having an arm positionable over a planarizing surface of a polishing pad;

a conditioning disk attached to the carrier assembly;

and an actuator capable of controlling an operating parameter of the conditioning disk;

a controller operatively coupled to the actuator, the controller operating the actuator to adjust the operating parameter of the conditioning disk as a function of a pad wear and conditioning model, the model comprising:

determining wafer material removal rate as a function of pad conditioning parameters including conditioning disk down force and conditioning disk rotation rate.

22. The apparatus of claim 21, wherein the wafer material removal rate is determined according to the equation:

$$\hat{y}_i = \rho_i x_i + I_i,$$

where $\hat{y}_i$ is the wafer material removal rate for a conditioning parameter $x_i$, $\rho_i$, is the slope and $I_i$ is the intercept of the curve of the defining the relationship between $\hat{y}_i$ and $x_i$.

23. The apparatus of claim 22, wherein the updated pad conditioning parameter, $x_{i+}$, is determined by solving the equation:

$$x_{i+} = \frac{\hat{y}_{i+} - I_i - \frac{W_i}{W_T} \cdot \Delta\hat{y}}{\rho_i},$$

where $\hat{y}_{i+}$ is the target wafer material removal rate, $W_i$ is the weighing factor for conditioning parameter $x_i$, and $\Delta y$ is the prediction error for wafer material removal rate.

24. The apparatus of claim 21, wherein the updated pad conditioning parameters are updated according to the equation $k = (k-1) + g * (k - (k-1))$, where $k$ is a measured wafer material removal rate, *k-1* is a calculated wafer material removal rate, $g$ is the estimate gain, and *(k-(k-1))* is the prediction error.

25. A method of developing a pad wear and pad conditioning model for optimization of the pad conditioning for polishing pads used to remove material from a wafer, comprising the steps of:

determining the relationship between at least one pad conditioning parameter and wafer material removal rate; and

determining maximum and minimum values for each of the at least one pad conditioning parameters and the wafer material removal rate; and

recording the relationships and minimum and maximum values of the at least one pad conditioning parameter and the wafer removal rate.

26. The method of claim 25, wherein the at least one pad conditioning parameter comprises a plurality of parameters and the wafer removal rate is defined as a weighted function of the plurality of pad conditioning parameters.

27. The method of claim 25, wherein the at least one pad conditioning parameters comprises conditioning disk down force.

28. The method of claim 27 wherein the at least one pad conditioning parameter further comprises conditioning disk rotational rate.

29. The method of claim 25, where the at least one pad conditioning parameter comprises one or more parameters selected from the group consisting of conditioning disk down force, conditioning disk rotational rate, frequency of conditioning, and conditioning disk translational speed.

30. The method of claim 25, wherein the relationship between the at least one conditioning parameter and wafer removal rate is determined by incrementally varying the conditioning parameter and measuring the resultant wafer removal rate.

31. The method of claim 25, wherein the maximum value for the conditioning parameter is the value above which no incremental increase of the wafer removal rate is observed.

32. The method of claim 25, wherein the minimum value for the conditioning parameter is the value which provides the minimum wafer removal rate.

33. The method of claim 25, further comprising the steps of:

polishing a wafer in the CMP apparatus under a first set of pad conditioning parameters selected to maintain wafer material removal rates within preselected minimum and maximum removal rates;

determining a wafer material removal rate occurring during said polishing step;

calculating updated pad conditioning parameters based upon said determined wafer material removal rate and the pad wear and conditioning model to maintain wafer material removal rates within the maximum and minimum removal rates; and

conditioning the polishing pad using the updated pad conditioning parameters.

34. The method of claim 33, wherein the updated pad conditioning parameters are calculated by determining the difference between an output of the pad wear and conditioning model and said determined wafer material removal.

35. The method of claim 33, wherein the updated pad conditioning parameters are updated according to the equation $k = (k-1) + g * (k - (k-1))$, where $k$ is a measured wafer material removal rate, $k_1$ is a calculated wafer material removal rate, $g$ is the estimate gain, and $(k-(k_1))$ is the prediction error.

36. A computer readable medium comprising instructions being executed by a computer, the instructions including a computer-implemented software application for a chemical mechanical polishing process, the instructions for implementing the process comprising the steps of:

a) receiving data from a chemical mechanical polishing tool relating to the wafer removal rate of at least one wafer processed in the chemical mechanical polishing process; and

b) calculating, from the data of step (a), updated pad conditioning parameters within defined maximum and minimum values, wherein the updated pad conditioning parameters are calculated by determining the difference between an output of a pad wear and conditioning model and the data of step (a).

37. A method of conditioning a planarizing surface in a chemical mechanical polishing (CMP) apparatus having a polishing pad against which a wafer is positioned for removal of material therefrom and a conditioning disk is positioned for conditioning of the polishing pad, comprising the steps of:

(a) developing a pad wear and pad conditioning model by:

(i) determining the relationship between at least one pad conditioning parameter and wafer material removal rate; and

(ii) determining maximum and minimum values for each of the at least one pad conditioning parameters and the wafer material removal rate; and

(ii) recording the relationships and minimum and maximum values of the at least one pad conditioning parameter and the wafer removal rate.

(b) polishing a wafer in the CMP apparatus under a first set of pad conditioning parameters selected to maintain wafer material removal rates within preselected minimum and maximum removal rates;

(c) determining a wafer material removal rate occurring during said polishing step;

(d) calculating updated pad conditioning parameters based upon said determined wafer material removal rate of said step (b) and the pad wear and conditioning model to maintain wafer material removal rates within the maximum and minimum removal rates,

wherein the wafer material removal rate is determined according to the equation:

$$\hat{y}_i = \rho_i x_i + I_i,$$

where $\hat{y}_i$ is the wafer material removal rate for a conditioning parameter $x_i$, $\rho_i$, is the slope and $I_i$ is the intercept of the curve of the defining the relationship between $\hat{y}_i$ and $x_I$, and the updated pad conditioning parameter, $x_{i+}$, is determined by solving the equation:

$$x_{i+} = \frac{\hat{y}_{i+} - I_i - \frac{W_i}{W_T} \cdot \Delta\hat{y}}{\rho_i},$$

where $\hat{y}_{i+}$ is the target wafer material removal rate, $W_i$ is the weighing factor for conditioning parameter $x_i$, and $\Delta y$ is the prediction error for wafer material removal rate; and

(e) conditioning the polishing pad using the updated conditioning parameters.

38. A system for conditioning a planarizing surface in a chemical mechanical polishing (CMP) apparatus having a polishing pad and a conditioning disk, comprising:

a) a pad wear and conditioning model that defines wafer material removal rate as a function of at least one pad conditioning parameters including rotation and direction of the conditioning disk;

b) polishing means for polishing a wafer in the CMP apparatus

c) measuring means for determining a wafer material removal rate; and

d) calculating means for updating pad conditioning parameters based upon said determined wafer material removal rate of said step (c) and the pad wear and conditioning model to maintain wafer material removal rates within the maximum and minimum removal rates.